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THE QUEENSLAND JOURNAL OF AGRICULTURAL SCIENCE

VOL. 2. NO. 3.

SEPTEMBER, 1945

AN ELECTRIC POLLINATOR FOR TOMATOES.

By W. COTTRELL-DORMER, M.Sc.Agr., Horticulturist, Horticulture Branch, Division of Plant Industry.

INTRODUCTION.

The instrument described below was designed when it became desirable to carry out large-scale field pollination experiments in a study of winter blossom-drop in tomatoes; it simulates the behaviour of a native bee (*Anthophora pulchra*) visiting tomato flowers. Essentially it consists of a fine wire loop which is caused to vibrate within a glass pollen-collecting chamber. By placing the staminal cone of the flower in the loop, and causing the latter to vibrate, pollen is rapidly shaken from the anthers into the chamber. Pollination is effected in the same manner; if the stigma is protruding it will pick up pollen from the bottom of the chamber; if the stigma is only partly exposed pollen will be thrown up on to it; if the flower contains loose pollen the vibration will add to the pollen in the chamber and at least ensure selfing should the stigma be too deep within the flower to be reached by pollen from the chamber. The instrument is of especial value in hybridization studies, since it can readily be sterilized and enables pollen to be collected from a number of varieties in different localities for use where desired. It is thought that the instrument could be used in the commercial production of F_1 hybrids, since it greatly reduces the time required to effect a cross and is not affected by ordinary winds. Though designed for use with tomatoes, the instrument can be used in its present form for collecting pollen from other flowers, and, where necessary, could readily be modified.

ORIGINATION OF DESIGN.

For many years it has been customary to pollinate tomatoes in the glasshouse by the so-called "watchglass" method described by Bailey (1895), Schneck (1928), and other workers. In this method pollen is obtained by tapping flowers over a watchglass or glass slide; the protruding pistils of the flowers to be pollinated are then dipped into the pollen. The method suffers from several disadvantages: only a relatively small proportion of the available pollen is secured, great care must be exercised not to blow or brush the pollen off the glass, and the pistil must definitely protrude for rapid pollination; for field work it is out of the question since the least gust of wind will disseminate the pollen. It is usual in the field to pollinate by applying an opened anther to the

stigma, as described by Hadfield and Calder (1936), or to transfer pollen from an anther to the stigma by means of a needle scalpel in the manner described by Barrons and Lucas (1942). These methods, though excellent for small-scale work, are relatively slow and wasteful of pollen and can only be used satisfactorily on still days or in the mornings before the wind rises.

During the course of a field study of winter blossom-drop in tomatoes in 1944 the writer found that, when blossom-drop was taking place on apparently healthy plants during cold and cloudy weather, fruit could be made to set by pollinating flowers by one of the methods described above. It was therefore decided that, if possible, large-scale field pollination experiments should be carried out during the following winter. It was realized, however, that a more rapid method of pollination would be required and one which would not be affected by the winds which usually prevail at that time of the year.

It had already been observed that even during a bad blossom-drop period an occasional flower would set fruit. It had also been noticed that a native, blue-banded, solitary bee (*Anthophora pulchra*) was at times active on tomato flowers. It seemed possible that this bee might have been a factor in the partial fruit-setting which had been observed, and its behaviour when visiting tomato flowers was therefore closely studied. The bee would alight on the staminal cone of a flower and grasp it firmly with its legs in such a manner that the medial portion of its abdomen was situated immediately below the tips of the anthers; it would then rapidly vibrate its wings, thereby causing vibration of the flower and discharge of pollen, which the bee caught with the pollen-collecting hairs on its abdomen. Unfortunately, the varieties on which the bee was operating at the time did not have protruding pistils, but it seemed inevitable that had this been the case the stigmas would have picked up pollen from the bee. These observations suggested that it should be possible to develop a much more convenient method of pollination than those referred to earlier; after a number of experiments the instrument described below was produced and found to be very satisfactory.

CONSTRUCTION.

Materials Required.

For each instrument the following materials are required:—

1 low-pitched buzzer, DC 3V, AC 5V, 1.3A.
1 radio "C" battery, 4½V.
1 piece ⅛-in. sheet ebonite.
1 pair discarded car distributor breaker points.
1 piece clock spring about ·015-in. thick (or a discarded Model "T" Ford car coil trembler plate).
2 screws 3/16-in. with one nut to fit.
5 screws ⅛-in. with four nuts to fit. (All screws perferably brass).
1 small piece pressure rubber tubing about ¼-in. bore.
1½ yds. two-wire "flex."

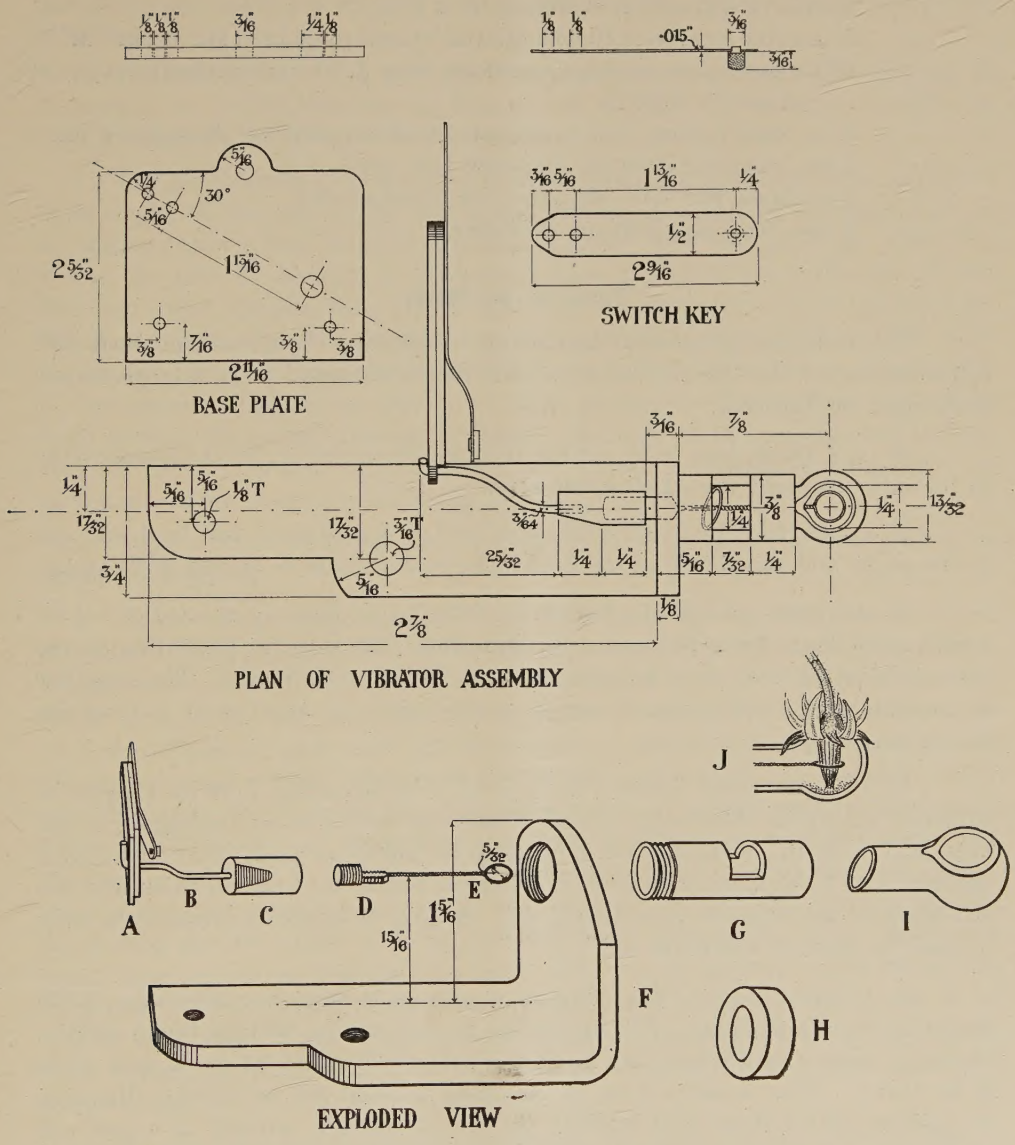


Figure 1.

Illustrating dimensions and disposition of parts of pollinator.

A Armature of buzzer.
B Connecting rod.
C Adaptor.
D Vibrator loop holder.
E Vibrator loop.
F Bracket support.
G Pollen chamber housing.
H Rubber ring.
I Pollen chamber.
J Position of flower during pollination or pollen extraction.

[*Drawings by William Manley.*

4½ ins. copper or brass strip ⅛ in. x ¾ in.
3 ins. fine steel wire 30-35 Imperial Standard gauge (Mandolin "E").
6 ins. soft glass tubing; minimum bore 3/16 in., maximum external diameter 9/32 in.
1-in. brass tubing; minimum bore 9/32 in., external diameter ⅜ in.
3 ins. steel rod 3/64 in. diameter (hat pin).
½-in. brass rod ⅛ in. diameter (or brass screw).
6 ins. brass rod 3/16 in. diameter.

Parts to be Made.

Following are given brief instructions regarding the making of parts and adjustments for the type of buzzer shown in Plates 1 and 2; letters given are those used in Figure 1.

A. A 3/64-in. hole to be drilled through the armature of the buzzer close to its outer end and through its mid-axis.

B. *Connecting Rod.*—The thin steel rod to be softened and bent and cut to the shape and size shown in the drawings; both ends to be tinned with solder.

C. *Adaptor.*—A 3/64-in. hole to be drilled ⅛-in. deep at one end of a ½-in. length of 3/16-in. brass rod and a 3/32-in. hole ¼ in. deep to be drilled at the other; the latter hole to be tapped with ⅛-in. Whitworth thread. The shoulder at one side of the non-threaded end to be filed away to avoid later fouling the buzzer cover.

D. *Vibrator Loop Holder.*—A piece of ⅛-in. brass rod 7/16 in. long to be threaded with ⅛-in. Whitworth thread at one end over ¼ in. of its length; a fine hole, say, 1/32 in., to be drilled ⅛ in. deep at the other end. The unthreaded portion then to be filed down to give a central flat blade 1/16 in. thick and the shoulders of the blade to be rounded off. A ⅛-in. Whitworth brass screw may be used in place of the brass rod.

E. *Vibrator Loop.*—The vibrator loop is made from fine steel wire, 30-35 Imperial Standard gauge. The new wire is first tinned with ordinary solder. Taking a piece about 3 ins. long a circular loop 5/32 in.-11/64 in. is now made at its centre. This is easily done by clamping a metal rod of suitable diameter in position over a flame and bending the wire around it quickly at a spot out of the flame where the rod is not quite red hot; removing the wire, its projecting ends are twisted together with the fingers to form a shank; the loop and its shank are now tinned once more.

F. *Bracket Support.*—This is a ⅛-in. brass or copper strip ¾ in. wide cut, bent, and tapped as shown in the drawings. The tappings on the basal portion are ⅛ in. and 3/16 in. Whitworth; that on the upright portion is ⅛ in. gas.

G. *Pollen Chamber Housing.*—A piece of brass piping ⅜ in. external diameter and 25/32 in. in length; one end to be threaded with ⅛ in. gas thread over about ⅛ in. of its length; the central portion to be slotted as shown in the

drawings; the other end may be countersunk to give good seating to the pollen chamber.

H. *Rubber Band.*—A slice cut from the pressure tubing; it is intended to fit around the pollen chamber housing and in the slot of the latter in order to hold the stem of the pollen chamber firmly.

I. *Pollen Chamber.*—A strong bulb with external diameter about 13/32 in. to be blown on the end of the soft glass tubing. The side of the bulb then to be opened; this is best done by grinding it down on a fine grinding wheel but it may be done by blowing and breaking off a second bulb on the side of the first one. The opening thus made should have a diameter of $\frac{1}{4}$ in. to 9/32 in. The depth of the chamber from this opening should be about 5/16 in. The tube is now cut $\frac{1}{2}$ in.-$\frac{5}{8}$ in. from the shoulders of the bulb to form a short stem, which is then ground obliquely so that it will later be easy to slip it below the rubber band around the pollen chamber housing. The edge of the opening in the bulb and the end of the stem are now carefully annealed without causing either to shrink any more than is unavoidable.

Base Plate.—This is made from $\frac{1}{8}$-in. sheet ebonite cut and drilled as shown in Figure 1.

Switch Key.—This is made from thin clock spring and presents little difficulty. Spring to be drawn flat by pulling around a smooth surface and a piece cut out with shears to the size and shape shown in Figure 1. The holes can now easily be made if their positions on the strip are each marked by a sharp blow on a centre punch; each mark will then show a "pimple" on the reverse side of the strip; each "pimple" then to be filed down until a small hole appears, which can be opened up by means of a fine rat-tail file. A press button is then made from 3/16-in. brass rod. Now a 3/16-in. hole is drilled in a piece of board and the button is placed in it with its flat end protruding slightly; then the spring strip is clamped on to the board with the single hole at one end pressing against the button and the latter soldered on to the strip through the hole. A contact point from an old car distributor breaker arm is then soldered on to the spring immediately above the press button. A small area of the spring is now to be tinned with solder immediately around the inner hole at the other end of the strip in order to provide a good contact when the switch key is later connected to the buzzer.

Spanner.—A small spanner for setting or removing the vibrator loop is made by cutting a 1/16-in. slot at the end of a short length of 3/16-in. brass rod.

Electrical Circuit.

A switch is included in the buzzer circuit in the manner shown in Plate 1. The screw which serves to hold in place the buzzer cover is taken out and its head filed down to leave a disc about 3/64 in. in depth, to the face of which is soldered another discarded distributor point. The longer end of the buzzer coil winding is now to be disconnected from its terminal and lengthened slightly if necessary; to this end is then soldered a $\frac{1}{8}$-in. brass nut after having

cut a small slot along its side to take the wire. The cover holding screw is now replaced and suitably connected with the terminal from which the coil winding was previously disconnected. A small piece of fine rubber insulating tube, which may be pulled off from the "flex," is then slipped over the other end of the coil winding to keep it separated from the end previously referred to. It will be found on assembling the instrument that the contact point on the switch key will come into position immediately below the contact point on the cover holder screw.

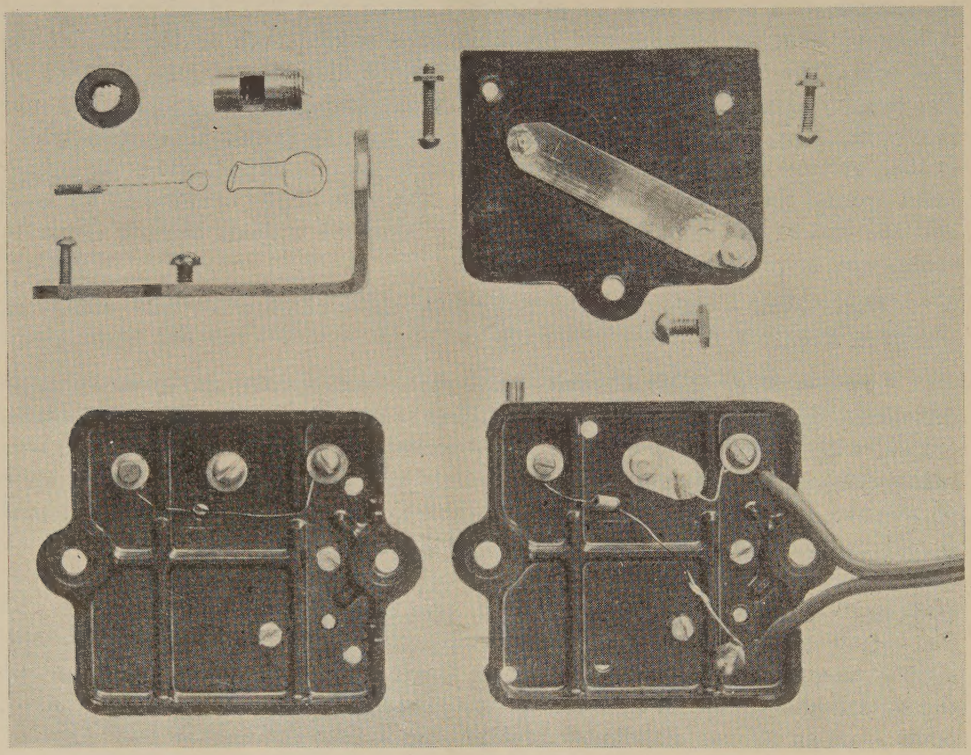


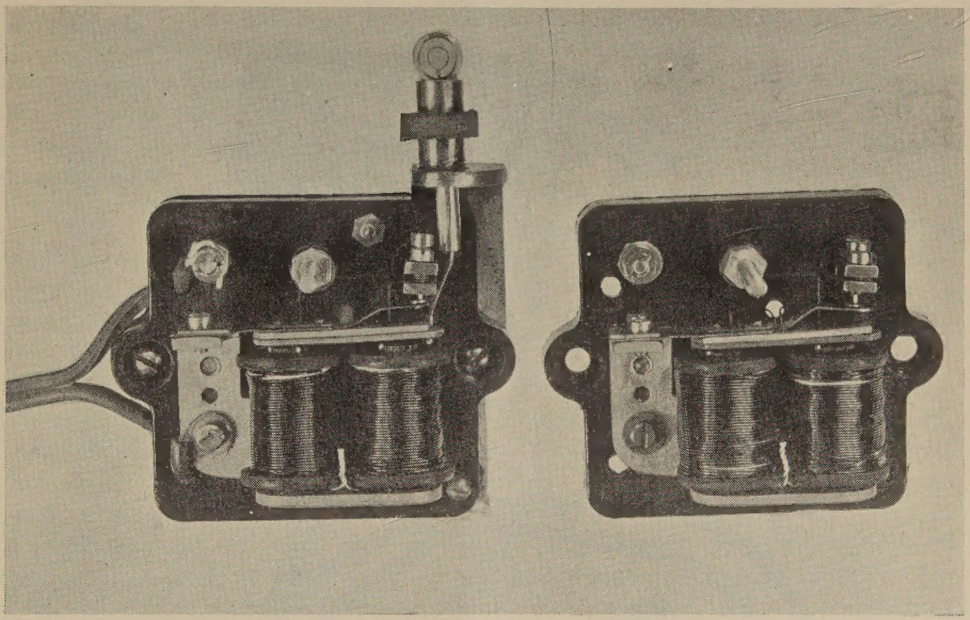
Plate 1.

Showing electrical circuit and component parts. In lower left corner is shown buzzer prior to modification.

[*Photograph by W. J. Sanderson.*

Assembly.

The parts of the instrument are now ready for assembly. First, the bracket support is screwed into position with a 3/16-in. screw. Next, the base plate is affixed with a 3/16-in. screw and nut so as to fit neatly against the bracket support. Now the positions are to be marked on the underside of the base of the buzzer for $\frac{1}{8}$-in. holes to be drilled to take the remaining screws for the base plate and bracket support. Having drilled these holes, after removing the base plate and bracket support, the two-wire "flex" is connected to the buzzer and the bracket support screwed into position again with its two screws. The switch key is now to be affixed to the base plate by means of a $\frac{1}{8}$-in. screw



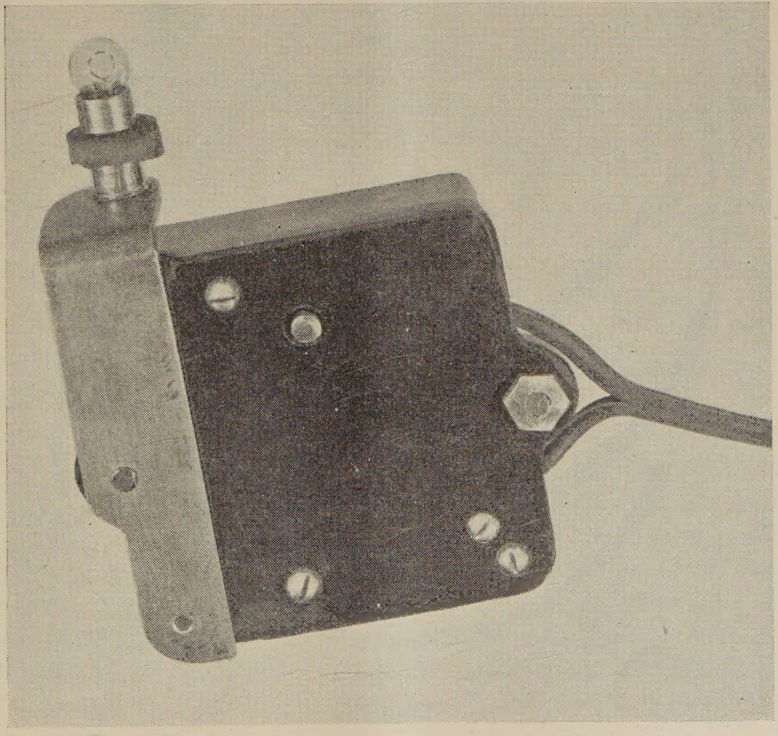


Plate 2.

Showing completed pollinator and unaltered buzzer without their covers, and underside of completed pollinator.

[*Photographs by W. J. Sanderson.*

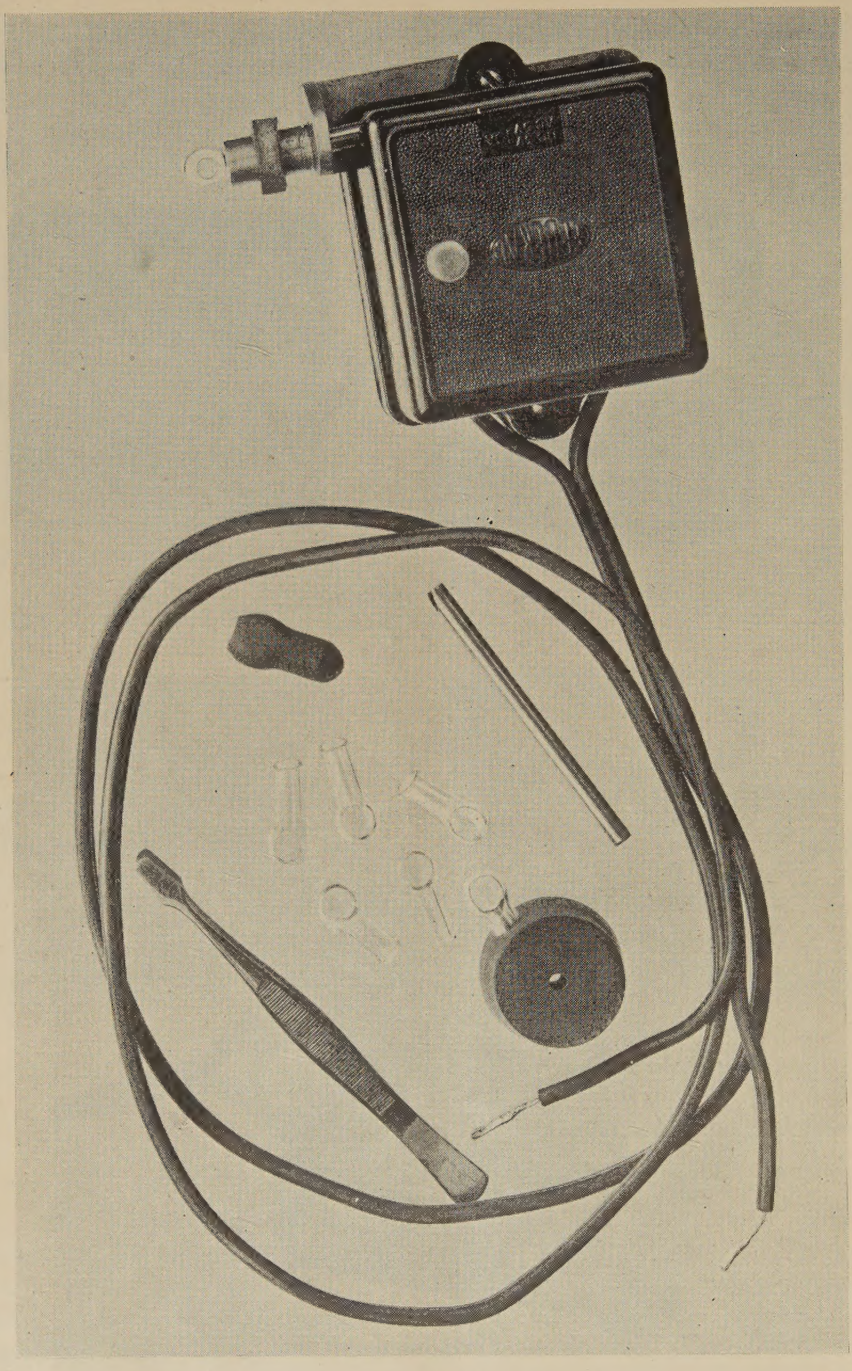


Plate 3.

Showing completed pollinator, together with small spanner, spare pollen chambers, pollen chamber in rubber sheath, hybridizing forceps, and pollen chamber held in rubber stopper.

[*Photograph by W. J. Sanderson.*

and nut through the end hole; then a second screw is passed through the remaining hole and screwed into the nut which was soldered to the end of the coil winding. The base plate can now be screwed into place with its 3/16-in. and two $\frac{1}{8}$-in. screws and nuts, all screws having previously been shortened where necessary. The connecting rod is then to be soldered on to the armature and the adaptor to the connecting rod.

Next the vibrator loop holder is to be screwed tightly into position in the adaptor and the pollen chamber housing screwed finger-tight into the bracket support. The buzzer should then be tested and adjusted as necessary to give a strong and fairly high frequency vibration. The vibrator loop holder should work freely in the centre of the inner end of the pollen chamber housing: if necessary, it can readily be adjusted by bending the connecting rod slightly. The vibrator loop should then be tried in position in its holder and, if necessary, its shank shortened so that the loop will be centred in and approximately level with the pollen chamber opening when at rest. Removing the pollen chamber housing, the shank is then soldered into position with the loop in a plane parallel to the base plate. If it is later found that the vibrator loop holder tends to become loose when the instrument is in use, the adaptor should be slotted for about two-thirds of its length with a fine jeweller's saw and the two sides pressed slightly together in a vise so that they will act as a spring clamp when the vibrator loop holder is again screwed into position. Having satisfactorily adjusted and fitted the vibrator loop, the rubber band is forced into position around the pollen chamber housing, the latter again screwed finger-tight into position, and the pollen chamber thrust home. The vibrator loop should now be at rest a little below the pollen chamber opening; if necessary, its shank can be bent at its base to bring it into this position. It now remains only to cut a slot in the corner of the bakelite cover of the buzzer to allow complete freedom of movement to the adaptor and the instrument is ready for use.

METHODS OF USE.

The instrument may be used as either a pollen collector or a pollinator. The methods of use for each purpose are given below.

Use as a Pollen Collector.

The instrument is designed for use in the field, glasshouse, etc., on growing plants; but, of course, it can equally well be used for collecting pollen from flowers brought into the laboratory. When it is used on growing plants, the wire flex is connected to the battery, one, two, or three cells being tapped according to the force of the vibration required; for tomato flowers the writer taps three cells, or $4\frac{1}{2}$ volts. The battery is then carried in the pocket, in a belt pouch, or in some other convenient manner. The instrument is held horizontally in the right hand with the thumb over the cover and the fingers on the underside in such a way that the tip of the second finger rests lightly on the switch press button. Continuing to hold the instrument more or less horizontally, it is placed

below the flower to be treated. Grasping the peduncle of the flower between the thumb and first finger of the left hand, as shown in Plate 4, the flower is brought into a vertical position and the staminal cone lowered into the vibrator loop as shown at "J" in Figure 1; a light press on the press button will then set the loop in motion and most of the loose pollen of the flower will be shaken into the pollen chamber in a few instants without injuring the flower or impairing its ability to set fruit. The whole operation takes only a few seconds, so the rate at which flowers can be treated is usually restricted only by the number of suitable flowers available. The best stage of anthesis at which to collect pollen is when the petals are about fully reflexed. One good flower of the Break o' Day variety of tomato will yield about 0·0006 gm. of pollen, or about 150,000 pollen grains, in a single

Plate 4.

Showing method of using pollinator in the field. Position of hands is a matter of convenience and will depend on position of flower.

[Photograph by W. J. Sanderson.

treatment; some varieties—e.g., Rouge de Marmande—will yield considerably more. The yield of pollen is influenced by the weather and the age and health of the plant; cluster varieties are far less affected by weather in this respect than are the larger-fruited varieties.

When sufficient pollen has been collected, or the pollen chamber has been sufficiently filled, the latter is removed from its housing, its stem plugged with a small piece of cotton wool, a rubber "policeman" or sheath slipped over it (see Plate 3) in order to prevent the pollen from falling out, and a clean pollen chamber fitted to the instrument. In a single test the writer was able successfully to fertilize emasculated flowers with pollen kept in a chamber and sheath for 30 hours at ordinary room temperatures; the percentage of viability was, however, not determined. As a matter of interest, pollen has been collected from a number of other flowers, including sweet pea, Iceland poppy, wallflower, citrus, custard apple, and papaw, using the instrument in its present form. It could easily be modified for special purposes, its basic principle being the shaking of anthers within a collecting chamber.

Use as a Pollinator.

As a pollinator in field or glasshouse the instrument, after being charged with pollen, is used precisely as described above. If the pistil of the flower is short and the anthers contain loose pollen, selfing at least will be ensured. If the pistil is longer and the stigma partly exposed, pollen will be thrown on to the latter by the rapid motion imparted to the anther tips by the vibrator loop. If the pistil is long and the stigma protrudes the latter will pick up pollen from the bottom of the chamber. When a variety which, owing to weather conditions other than rain, has a scanty supply of pollen is being pollinated, an ample supply of pollen can usually be obtained from a cluster variety such as Prosperity if cross fertilization is of no consequence and fruit production only is desired. Experiments are at present in progress to determine to what extent, under such circumstances, pollen is driven up the staminal cone to reach a short pistil.

Used for experimental hybridization the pollen chamber, charged with pollen, is removed from its housing and its stem plugged with cotton wool, or removed from its rubber sheath if the pollen has been collected elsewhere and transported. Its stem is then thrust into a hole cut in the side of a medium-sized rubber stopper for ease of handling, as shown in Plate 3. Emasculation of the flower to be pollinated is best carried out by seizing the bases of two petals together by means of a pair of flat-nosed forceps and gently pulling out the corolla with the staminal cone as described by Barrons and Lucas (1942). The exposed pistil is then dipped into the pollen in the pollen chamber. It should be noted that the ready accessibility of the pollen chamber, the pollen chamber housing, and the vibrator loop make it an easy matter to sterilize these with alcohol where it is necessary to ensure purity of pollen in genetical studies. For large scale hybridization the charged pollen chamber can very conveniently be used in the following manner:—Two holes are bored close together and at right angles to each other and to its axis through a small rubber stopper.

Through the lower hole is passed a rubber band and the two protruding loops of the latter are slipped over the middle of the first finger of the left hand so as to hold the stopper across the inside of the finger; the rubber band should be of a size suitable to hold the stopper comfortably on the finger without its feeling tight. The pollen chamber stem is then thrust into the upper hole in the stopper,

Plate 5.

Showing method of using pollen chamber in large scale hybridization. Pistil of emasculated flower is about to be dipped into pollen in the pollen chamber.

[*Photograph by W. J. Sanderson.*

where it can safely and conveniently be carried. Emasculation of each flower is carried out as described in the previous paragraph and is not interfered with by the presence of the pollen chamber. Immediately after each emasculation the forceps in the right hand are moved into the palm of that hand, the peduncle

of the flower seized with the fingers and the pistil dipped into the pollen chamber as shown in Plate 5. The whole of this operation occupies from seven to 15 seconds according to the ease with which the corolla may be removed from the flower. The latter operation is best performed just before dehiscence, since the corolla is then easier to remove and the stigma is more receptive than in younger flowers. The right stage at which to emasculate is soon determined at the commencement of the work by examining a few flowers for dehiscence with a 10x hand lens. It should also be mentioned that the work is simplified if the female parent plants are staked and pruned to one stem and if a group of male parent plants is grown nearby to provide a convenient source of pollen.

This method of hybridizing tomatoes is a great deal more rapid than any other known to the writer and is not affected by ordinary winds; the instrument may therefore prove useful with this crop in the commercialization of hybrid vigour, the advocacy of which periodically appears in the literature. It is perhaps of interest to mention that experiments are under way to determine whether successful cross-pollination of varieties with protruding pistils can be accomplished without emasculation, as this would further reduce the time factor in commercial hybridization.

REFERENCES.

BAILEY, L. H. 1895. Plant Breeding. New York: MacMillan and Co.

BARRONS, K. C., and LUCAS, H. E. 1942. The production of first generation hybrid seed for commercial planting. Proc. Am. Soc. Hort. Sci. 40: 395-404.

SCHNECK, H W. 1928. Pollination of greenhouse tomatoes. Cornell Agric. Expt. Sta. Bull. 470.

HADFIELD, J. W., and CALDER, R. A. 1936. Commercialization of hybrid-vigour in the tomato. N.Z. J. Agric. 53: 139-46.

A COMPARISON OF SOIL NITRATE NITROGEN VALUES UNDER BARE FALLOW AND AFTER PLOUGHING IN VARIOUS PERENNIAL TROPICAL LEGUMES AND COWPEAS.

By J. L. SCHOFIELD *, B.Sc. (Manc.), Agrostologist, Agriculture Branch, Division of Plant Industry.

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SUMMARY.

1. Four perennial tropical legumes—Calopogonium mucunoides (calopo), Centrosema pubescens (centro), Pueraria phaseoloides (puero) and Stylosanthes guianensis (stylo)—after 18 months' growth were ploughed under in July at South Johnstone, on the wet tropical coast of Queensland, and soil nitrate nitrogen values were determined in four layers to a depth of 24 inches over the ensuing seven months.

2. The mean nitrate nitrogen values for the puero plots at each depth were significantly higher at the 1 per cent. level than the corresponding values for the other plots. In the top six inches of the puero plots, the mean value was 171.8 p.p.m., and the maximum was 395.6 p.p.m. in early October.

3. The effects of yield, chemical composition of the plant material, soil moisture and temperature on nitrate nitrogen production are discussed. A high positive correlation between precipitation and leaching of nitrate is shown.

4. Comparison with a ploughed-in area of giant cowpeas showed that only puero was superior to cowpeas in soil nitrate production.

* Formerly Director, Bureau of Tropical Agriculture.

5. Under bare fallow, nitrate nitrogen production was not detected until mid-August and was slow until mid-September. The maximum content of 108.0 p.p.m. in the top six inches was reached in mid-January, and the mean value in that layer over seven months was 34.4 p.p.m.

6. The importance of perennial legumes as soil improving plants in the tropics is stressed and the particular value of puero and centro is indicated.

7. The implications of nitrate nitrogen production under bare fallow in relation to pasture and crop growth are discussed.

INTRODUCTION.

The problem of building up soil fertility is particularly important in coastal Queensland, where the climatic conditions favour erosion and the practice of monoculture is common. Two of the main limiting factors in satisfactory plant growth on worn-out soils are the low content of available nitrogen and the lack of that "crumb" structure in the soil which has been referred to as "the only structure having any agricultural value at all."

The subject of green-manuring under tropical conditions is one about which much has been written and concerning the value of which widely divergent views exist. Russell (1936) summed up the position as follows:— "Green manuring is very variable in its effects; indeed probably no other method of manuring the land has so wide a range of possibilities. It may be exceedingly effective, or on the other hand it may be almost useless." Joachim (1931) observed that in Ceylon green-manuring has come to be recognized as an essential agricultural operation on tea, and to a lesser extent on rubber plantations, and listed the chief advantages of the practice. Faulkner (1934) reported results obtained with the annual, *Mucuna utilis,* as a green manure at Ibadan, Southern Nigeria, where the rainfall is heavy and prolonged and the land light. Gethin Jones (1942) pointed out the promise shown by *Glycine javanica* as a permanent cover crop in Kenya.

The effects of the decomposition products of green manures on crop yields have been studied fairly extensively, but in tropical countries little has been done to examine the primary causes of subsequent increased crop yields, namely, the accretion of nitrogen and of humus supplies. The investigation reported in this paper was undertaken at the Bureau of Tropical Agriculture at South Johnstone in order to determine the effect of various green manures on the nitrate nitrogen content of the soil under the climatic conditions of the "wet belt" of coastal northern Queensland.

SCOPE OF THE INVESTIGATION.

The nitrate nitrogen values in the soil, at 6-inch depths down to 24 inches, which resulted from the ploughing under of four promising introduced perennial legumes—*Calopogonium mucunoides* Desv. (calopo), *Centrosema pubescens* Benth. (centro), *Pueraria phaseoloides* Benth. (puero) and

Stylosanthes guianensis Sw. (stylo)—allowed to grow for 18 months, were compared with the corresponding figures obtained from a bare fallow. A supplementary investigation included the determination of nitrate nitrogen figures following ploughing under of giant cowpeas (*Vigna unguiculata* Walp.) on an adjacent area. These determinations were carried out at intervals from the end of the wet season of 1940-41 to the onset of the next wet season, a period of about 7 months, as a first step in the intensive study of the relative merits of these plants as builders of soil fertility in the tropical "wet belt" and as components in a system of mixed farming.

Descriptions of the legumes, of the experimental area and of the soil and fertilizer treatments given, together with climatological data, have been given in previous papers (Schofield, 1941, 1944).

Under the climatic conditions of the wet tropical belt, calopo, centro and puero after satisfactory establishment (which generally entails inter-row scarification and hoeing until a thick cover is obtained) act as self-mulching covers, and do not form woody material. Stylo, when allowed to grow unrestrictedly, becomes very coarse and forms woody stems at the base; it is not to be expected, therefore, that this legume will be as satisfactory as the other three as a long-term green manure. All of the legumes may be ploughed under at any time after 18 months to fit in with the requirements of the rotation. They can also be used as grazing crops. This flexibility allows of their use over extended periods and for diversified purposes, and is a characteristic which is likely to prove of importance under the erratic climatic conditions of coastal Queensland.

TECHNIQUE.

Establishment.

In early February, 1940 duplicate plots of calopo, centro and puero were planted at the rate of 4 lb. of seed per acre, and of stylo at the rate of 2 lb. per acre. The plot size was 34 feet by 6 feet and planting was carried out in two parallel rows 3 feet apart. Fallow plots were included, and these were clean-weeded at intervals throughout the experiment. The layout was a 5 x 2 randomized block. Germination of the seeds was rapid and all of the legumes quickly established a thick cover. Weeding of the legumes was carried out twice before the heavy rains set in and the legumes were then left undisturbed, except for occasional weeding, until July, 1941.

Method of Soil Sampling.

Six days after the legumes had been ploughed under, soil samples were taken at four separate 6-inch depths—0-6 inches, 6-12 inches, 12-18 inches, and 18-24 inches—and similar sampling was carried out in the bare fallow plots. Four samples were taken from each plot at each depth and bulked. After collection, the samples were taken to the laboratory and treated immediately to arrest nitrification. Nitrate determinations were made by the phenol-disulphonic

Table 1.

NITRATE NITROGEN (MEAN OF TWO DETERMINATIONS) IN EACH LAYER OF SOIL IN EACH TREATMENT DURING A PERIOD OF SEVEN MONTHS.

Treatment.	Soil Layer. Inches.	Date of Sampling and Nitrogen in Parts per Million.													
		July 8	Aug. 4	Aug. 14	Aug. 28	Sept. 9	Sept. 19	Oct. 1	Oct. 13	Oct. 27	Nov. 11	Nov. 28	Dec. 24	Jan. 13	Feb. 2	Mean.
Fallow	0– 6	nil	nil	5·2	8·4	11·8	22·4	40·0	51·9	85·0	10·1	18·7	77·1	108·0	42·7	34·4
	6–12	nil	nil	4·1	4·6	10·9	17·6	29·9	18·7	25·0	41·7	18·2	46·2	42·4	38·3	21·3
	12–18	nil	nil	1·2	nil	2·2	4·1	10·9	5·0	5·4	20·5	13·3	27·5	18·3	26·9	9·7
	18–24	nil	nil	nil	nil	nil	1·4	2·7	3·6	4·4	4·9	4·7	8·5	6·3	13·8	3·6
Calopo	0– 6	4·3	3·5	39·2	49·0	42·0	81·6	96·7	103·2	119·8	22·8	42·0	121·5	187·0	21·6	66·7
	6–12	2·6	17·1	34·3	44·0	55·7	92·0	83·6	73·0	95·0	151·2	57·0	120·5	128·5	63·5	72·7
	12–18	1·6	4·5	7·2	4·8	15·3	17·0	21·2	11·5	10·8	56·1	26·8	48·3	56·1	38·6	22·8
	18–24	2·4	nil	1·2	3·4	2·6	13·5	5·5	4·1	13·1	12·0	7·2	18·6	13·1	14·4	7·9
Centro	0– 6	15·2	5·3	20·2	30·5	40·4	73·7	203·2	219·5	141·3	31·5	15·2	74·3	91·4	42·4	71·7
	6–12	9·1	13·8	26·4	26·6	61·7	67·7	88·0	64·5	46·3	102·2	49·0	82·3	70·3	71·0	55·6
	12–18	3·3	6·5	7·4	7·9	12·2	17·3	34·6	8·9	10·3	51·2	17·9	43·4	35·6	41·7	21·3
	18–24	2·4	1·6	3·3	2·7	4·5	10·9	13·0	11·1	4·6	17·6	5·0	10·3	7·0	20·8	8·2
Puero	0– 6	9·8	69·0	110·0	169·0	130·0	144·2	395·6	378·2	335·0	48·4	120·0	198·5	253·5	43·7	171·8
	6–12	8·5	90·0	90·6	143·0	164·5	180·0	151·0	167·5	125·2	255·0	262·0	146·5	199·0	190·7	155·2
	12–18	4·1	10·8	16·3	14·1	24·9	33·8	30·9	39·6	29·0	134·7	130·5	78·0	79·5	115·0	52·9
	18–24	4·0	3·3	4·0	14·9	5·0	10·3	22·6	48·3	12·9	22·8	35·8	26·1	19·5	44·2	19·5
Stylo	0– 6	2·1	2·0	22·3	27·5	33·5	82·8	85·0	80·0	120·7	42·5	9·1	94·7	134·5	26·2	54·5
	6–12	2·1	13·7	66·6	32·4	59·7	97·2	76·8	86·2	47·8	67·0	38·9	69·0	67·8	61·2	56·2
	12–18	1·5	nil	7·0	5·4	30·1	29·1	23·1	23·0	13·4	35·2	24·5	34·2	32·4	41·2	21·4
	18–24	0·8	nil	nil	5·5	nil	11·9	7·4	20·3	5·3	11·5	3·8	9·2	4·3	12·0	6·6
Rainfall between Sampling Dates in Inches		nil	1·73	nil	nil	1·13	nil	nil	0·02	nil	5·14	1·09	2·01	0·72	5·72	..

acid method, the results being expressed as parts per million of nitrogen in the dry soil. Sampling at intervals ranging from 10 days to 27 days was continued for a period of approximately seven months, at the end of which time the heavy rains characteristic of the beginning of the wet season in the South Johnstone area commenced.

A similar system of soil sampling to that employed for the perennial legumes was carried out on alternate dates on an adjacent area of giant cowpeas which had been ploughed under. The cowpeas formed a good cover, with green matter estimated at 12-15 tons per acre.

COMPARISON OF NITROGEN AFTER PERENNIAL TROPICAL LEGUMES AND UNDER BARE FALLOW.

The legumes were ploughed under on July 2, 1941, and the first nitrate determinations were made six days later. Table 1 summarizes the results and a graphical representation of nitrate nitrogen at each depth throughout the experiment is shown in Figures 1-4.

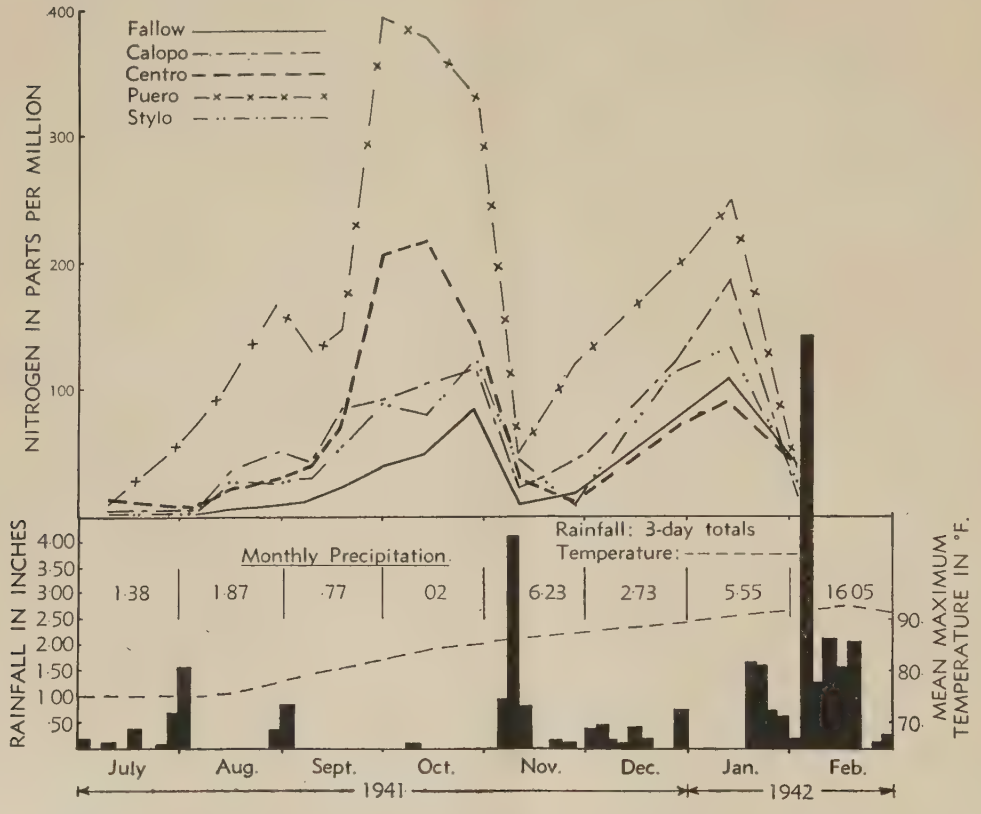

Figure 1.

Showing nitrate nitrogen in the 0-6 inch layer of soil in each treatment, with rainfall in 3-day totals and the mean maximum monthly temperatures.

Nitrate Nitrogen in the 0–6 inch Layer.

On August 4, the mean nitrate nitrogen figure obtained from the puero plots was 69 p.p.m., compared with calopo 3·5 p.p.m., centro 5·3 p.p.m., stylo 2·0 p.p.m. and bare fallow nil. Ten days later, the soil in the puero plots contained 110 p.p.m., compared with calopo 39.2 p.p.m., centro 20·2 p.p.m., stylo 22·3 p.p.m. and bare fallow 5·2 p.p.m. By August 28, the first peak was reached in the puero plots, the mean figure being 169 p.p.m. Between August 28 and September 9—the next sampling date—1·13 inches of rain were recorded, and this precipitation was responsible for leaching nitrates from the 0-6 inch layer to the deeper layers (see Figures 1 and 2).

On October 1—a little more than 12 weeks from the date of ploughing-in the green manures—the second and highest peak value for nitrate nitrogen in the puero plots was reached, namely, 395·6 p.p.m. Centro attained its peak with a figure of 219·5 p.p.m. on October 13. The corresponding values on October 1 in the other treatments were :—Calopo 96·7, centro 203·2, stylo 85·0 and bare fallow 40·0. Nitrate production remained at a high level in all treatments throughout October, November, December and January, months of high temperature and relatively low precipitation, until the commencement of the wet season in early February. Between October 27 and November 11, rainfall amounting to 5·14 inches was recorded, and considerable leaching of surface nitrates occurred, especially in the puero plots. On October 27 there were 335 p.p.m. of nitrate nitrogen in the surface 6 inches of the puero plots, but by November 11 the figure had receded to 48·4 p.p.m., whereas the corresponding values in the 6-12 inch layer were 125·2 and 255·0 p.p.m. respectively.

It is of interest to note the high positive correlation which exists between precipitation and the leaching of nitrate nitrogen from the surface 6 inches to the lower layers of soil as shown by a comparison of Figures 1, 2 and 3. Each reduction in nitrate nitrogen caused by rainfall-leaching in Figure 1 is represented in Figure 2 by a proportionate increase, and after heavy rainfall—as, for example, during the first fortnight of November, when 5.96 inches were recorded—there is a marked peak in the 6–12 inch and 12–18 inch layers, as shown in Figures 2 and 3. A third peak was reached in the puero plots on January 13, with 253·5 p.p.m.; the corresponding values in the other treatments were calopo 187, centro 91·4, stylo 134·5 and bare fallow 108. This last value approximates to the figure of 105 p.p.m. found by Thompson and Coup (1943) in the soil of a bare-ground control plot under New Zealand conditions.

A further point is that a peak of nitrate nitrogen in all plots is reached before October 27, but centro and puero are distinctly more effective during this period than are calopo and stylo. The plots of the first two legumes reached their maximum content of nitrate nitrogen before mid-October, whereas the calopo and stylo plots do not attain their maxima until January 13, a date which also marks the zenith nitrate nitrogen value for bare fallow.

The mean values for nitrate nitrogen in the different treatments have been examined by the method of analysis of variance, and the F value for

varieties was found to be 16·94, which is highly significant. The results are summarized in Table 2. Figure 1 shows the pattern of nitrate nitrogen content from July to February, together with the rainfall and temperature data for that period.

Table 2.

Mean Values for Nitrate Nitrogen in the 0–6 inch Layer of Soil in the Various Treatments.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen, p.p.m.	Percentage of Mean.
Fallow	4–8–41 to 2–2–42	14	34·4	43·1
Calopo			66·7	83·6
Centro			71·7	89·9
Puero			171·8	215·2
Stylo			54·5	68·3
General Mean	..	..	79·8	100·0
S.E. Mean of two ..	..	..	13·0	16·2
Sig. diff. P. = 0·05				63·8
Sig. diff. P. = 0·01				105·8

Conclusion : Puero > all others (1 % level).

Reference to Table 1 shows that, apart from the first and last sampling dates (July 8 and Feb. 2), nitrate nitrogen values in the puero plots at each depth are much higher than the corresponding values for other treatments. The mean value for the puero plots at each depth exceeds the highest of the other treatments by over 100 per cent. Cochran (1938) has pointed out that it is a good rule "to omit from the main analysis treatment which yield consistently more than double or less than half the main group of treatments." This method has been applied to the figures in this experiment, but no additional information of value was obtained.

The outstanding points of interest relative to the nitrate nitrogen content of the 0–6 inch layer which may be deduced from an examination of the data are as follows:—

(1) The very rapid rate of production of large amounts of nitrate nitrogen in the puero plots throughout the experiment, which extended over nearly seven months.

(2) The high production during October in the puero and centro plots.

(3) The relatively high production during January in the calopo plots.

(4) The increase from October to January which occurs in the fallow plots.

(5) The considerable amount of leaching from the surface 6 inches to the lower soil layers caused by rainfall on the light silty soil (40 per cent. fine sand, 31 per cent. silt, 16 per cent. clay).

Nitrate Nitrogen in the 6–12 inch Layer.

The nitrate nitrogen determinations on samples taken at 6–12 inches below the surface are summarized in Table 3 and the results are shown graphically in Figure 2. The means have been analysed statistically and the F value for varieties was found to be 209·97, which is very highly significant.

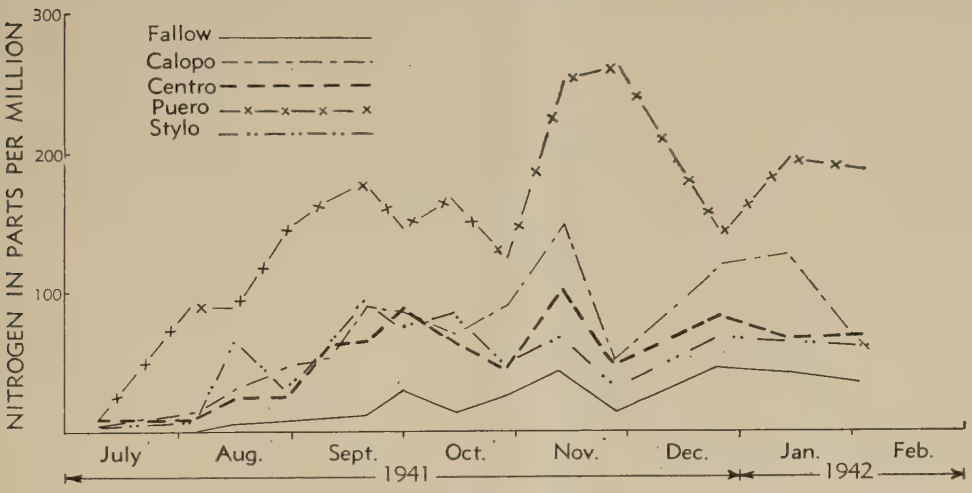

Figure 2.

Showing nitrate nitrogen in the 6-12 inch layer of soil in each treatment.

Table 3.

Mean Values for Nitrate Nitrogen in the 6–12 inch Layer of Soil in the Various Treatments.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen, p.p.m.	Percentage of Mean.
Fallow	4–8–41 to 2–2–42	14	21·2	29·4
Calopo			72·7	100·7
Centro			55·6	77·1
Puero			155·2	215·0
Stylo			56·2	77·8
General Mean	..	..	72·2	100·0
S.E. Mean of two ..	..	..	3·5	4·8
Sig. diff. P. = 0·05				18·8
Sig. diff. P. = 0·01				31·1

Conclusions : (1) Puero > all others (1% level); (2) Calopo, Centro, Stylo > Fallow (1% level); (3) Calopo > Centro, Stylo (5% level).

The nitrate nitrogen content in all treatments follows the same general trend throughout. The very high concentration in the 6–12 inch layer from late July to early February, and in particular from November to early February, indicates the remarkably high degree of nitrification which is occurring in the puero plots. A maximum content of 262 p.p.m. was reached on November 28, following heavy rains in the first half of the month.

The nitrate nitrogen content in the calopo plots follows a similar pattern to that of the puero plots, but the level is much lower. The maximum content was reached on November 11, when 151·2 p.p.m. was registered. The centro plot reached its maximum on the same date, with 102·2 p.p.m. The stylo plots, however, attained their maximum on September 19, with 97·2 p.p.m. The fallow plots show a steady increase from early August to early February, with peaks of 29·9 p.p.m. on October 1, 41·7 p.p.m. on November 11, and 46·2 p.p.m. on December 24.

Nitrate Nitrogen in the 12–18 inch Layer.

The means of the determinations of nitrate nitrogen in the 12–18 inch layer are given in Table 4 and the data is shown graphically in Figure 3. The figures have been statistically analysed: the F value for varieties was found to be 29·42, which is highly significant.

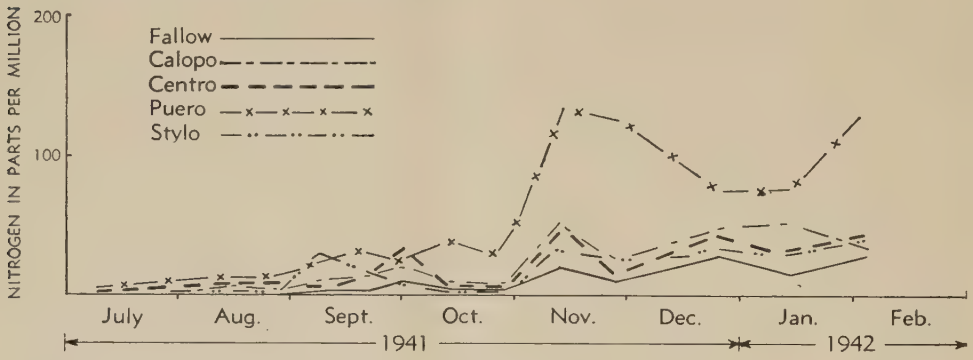

Figure 3.

Showing nitrate nitrogen in the 12-18 inch layer of soil in each treatment.

Table 4.

Mean Values for Nitrate Nitrogen in the 12–18 inch Layer of Soil in the Various Treatments.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen, p.p.m.	Percentage of Mean.
Fallow	4–8–41 to 2–2–42	14	9·6	37·6
Calopo			22·8	89·1
Centro			21·3	83·0
Puero			52·9	206·4
Stylo			21·5	83·8
General Mean	..	..	25·6	100·0
S.E. Mean of two ..	..	..	3·0	11·6
Sig. diff. P. = 0·05				45·6
Sig. diff. P. = 0·01				75·6

Conclusions : (1) Puero > all others (1% level); (2) Calopo, Stylo > Fallow (5% level); (3) difference between Centro and Fallow is approaching significance (5% level).

Nitrate Nitrogen in the 18–24 inch Layer.

Table 5 shows the means of nitrate nitrogen content in the 18–24 inch layer, and the data are shown graphically in Figure 4. The F value for varieties was found on statistical analysis to be 47·21, which is highly significant.

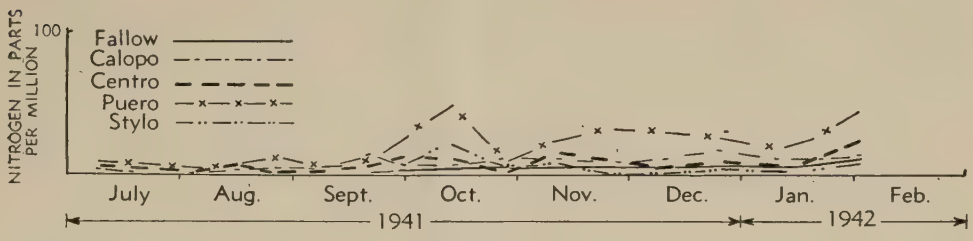

Figure 4.

Showing nitrate nitrogen in the 18-24 inch layer of soil in each treatment.

Table 5.

MEAN VALUES FOR NITRATE NITROGEN IN THE 18–24 INCH LAYER OF SOIL IN THE VARIOUS TREATMENTS.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen, p.p.m.	Percentage of Mean.
Fallow	4–8–41 to 2–2–42	14	3·6	39·2
Calopo			8·0	87·1
Centro			8·2	89·2
Puero			19·6	212·7
Stylo			6·6	71·8
General Mean	..	..	9·2	100·0
S.E. Mean of two ..	..	..	0·9	9·6
Sig. diff. P. = 0·05				37·8
Sig. diff. P. = 0·01				62·6

Conclusions : (1) Puero > all others (1% level); (2) Calopo, Centro > Fallow (5% level).

DISCUSSION OF FACTORS AFFECTING NITRATE PRODUCTION.

The main factors which affect nitrification, apart from the soil type, are the bulk and the composition of the green manure at the time of ploughing under (both of which are influenced by the efficiency of the associated symbiotic nitrogen-fixing organisms), and the soil moisture content and temperature throughout the period of decomposition.

Yield.

Duplicate quadrat cuts from each plot of the four legumes were made on July 2, 1941 so that an estimate of the yield of green matter could be calculated before the legumes were ploughed under. The respective yields of green matter in pounds per plot calculated from the mean of four quadrat cuts for each legume are given in Table 6.

Table 6.

Calculated Yield of Green Matter.

Legume.	Yield in Lb. of Green Matter per Plot.	Percentage of Mean.
Calopo	286	87·6
Centro	239	73·2
Puero	527	161·4
Stylo	254	77·8

These figures include a small, but practically negligible amount, of dead leaves which had accumulated under the legumes, particularly in the calopo, centro and puero plots. The quantity of dead foliage was very small for two reasons: (1) the quadrat cuts were taken at the end of the wet season, and (2) the legumes had been established for less than 18 months.

An outstanding feature of the yields is the large amount of green matter obtained from puero in comparison with the other legumes. As a matter of interest, it may be mentioned that yields varying from 7·0 to 9·1 tons of green matter per acre have been recorded at South Johnstone for stylo at the fourth cut, 18 months after planting; and that after 5 years (in February, 1945) puero carried foliage estimated (mean of five quadrat cuts) at 11·5 tons of green matter and provided 18.8 tons of mulch per acre.

Chemical Composition of the Plant Material.

Chemical analyses of the perennial legumes employed have been carried out at the Bureau of Tropical Agriculture and in the Agricultural Chemical Laboratory of the Department of Agriculture and Stock on numerous occasions, and typical figures are set out in Table 7.

Table 7.

Percentage Composition on a Moisture-free Basis of Calopo, Centro, Puero, and Stylo Grown at South Johnstone.

Legume.	N.	Protein. (N. x 6·25)	Fat.	Carbo-hydrates.	Fibre.	Ash.	CaO.	P_2O_5
Calopo	3·1	19·5	1·2	40·2	31·1	8·0	2·117	0·584
Centro	3·0	18·7	3·0	38·4	30·3	9·6	2·590	0·802
Puero	3·1	19·5	1·2	38·6	34·2	6·5	1·047	0·607
Stylo (old) ..	2·3	14·6	1·3	37·8	38·6	7·7	1·505	0·570

The figures show that calopo, centro and puero contain considerably more nitrogen than stylo, but that stylo possesses the highest fibre content. Waksman (1932) stated:—"Whenever a readily available source of nitrogen is wanted immediately, substances containing less than 2 per cent. nitrogen cannot be profitably used. The greater the nitrogen content of a material, the greater is its value as an immediate source of nitrogen." Parbury and Swaby (1942),

reporting the results of experiments with a large number of plants, stated that "an early return of nitrogen, coinciding with the demands of crops planted soon after their incorporation, was secured only when the nitrogen content of materials was above 2·5 per cent."

The carbon : nitrogen ratio of the plant material also affects nitrate production, and Akhurst (1932) suggested that a ratio considerably below 18:1 is necessary under tropical conditions for nitrification to take place. For Calopogonium and Centrosema he has calculated ratios as shown in Table 8. No figure is available for puero, but the fact that this legume produced extremely large quantities of nitrate nitrogen when turned under indicates that the relatively large amount of green matter was readily decomposed.

Table 8.

C : N Ratio of the Leaves and Stems of Calopogonium and Centrosema (from Akhurst, 1932).

Leaves.			Stems.		
Per Cent. N.	Plant.	C/N.	Per Cent. N.	Plant.	C/N.
4·47	Calopogonium	10·3	2·52	Calopogonium	17·3
4·38	Centrosema	10·6	3·03	Centrosema	14·2

The equivalent weights of nitrogen, P_2O_5 and CaO per plot have been calculated on the basis of a 35 per cent. dry matter content (dry matter figures exceeding 35 per cent. have been recorded for some of the legumes at South Johnstone for the drier months of the year) and the results are given in Table 9.

Table 9.

Equivalent Dry Matter Weights per Plot of N, P_2O_5 and CaO for Calopo, Centro, Puero and Stylo.

Legume.	Yield of Dry Matter in Pounds per Plot. (35 Per Cent. Basis.)	Equivalent Weight in Pounds per Plot.		
		N.	P_2O_5	CaO.
Calopo	100·1	3·1	0·58	2·12
Centro	83·6	2·5	0·67	2·16
Puero	184·4	5·7	1·12	1·93
Stylo	88·9	2·0	0·51	1·34

These figures demonstrate the remarkably high nitrogen and P_2O_5 equivalent weights obtained from puero. The CaO figure for puero is rather low at 1.047 per cent., as contents approximating to 2·0 per cent. have been obtained in a number of analyses.

It is well known that nitrification may be adversely affected by a relative poverty in available phosphoric acid, and it can be expected, therefore, that a high concentration of P_2O_5 in the green material turned under in the puero plots

will assist nitrification to a considerable degree, even though this soil is low in phosphate. Similarly, the lime application referred to previously and the lime content of the legumes will assist nitrification.

Symbiotic Nitrogen Fixation.

No investigation of the efficiency of the nitrogen-fixing organisms associated with the various legumes was made. Trials carried out prior to the initiation of the experiment (Schofield, 1941) indicated that inoculation of the seed of the species used in the experiment did not result in increased growth or vigour as compared with plants raised from uninoculated seed. It was concluded that the soil did not lack appropriate strains of Rhizobia.

In this connexion, it is of interest to review briefly published work on the status of root nodule bacteria of the species of legumes concerned. Allen and Allen (1936, 1939) placed stylo in the cowpea group. Beeley (1938), working in Malaya, showed that Rhizobium isolated from puero produced no nodulation or other beneficial effect when inoculated on the roots of centro. Aquina and Madamba (1939) in the Philippines demonstrated that nodule bacteria from calopo produced fairly abundant nodules on cowpea. Posadas (1941) placed puero in the cowpea group, and showed that the puero strain of Rhizobium fixed less nitrogen than strains isolated from two species of *Crotalaria* and two species of *Tephrosia*.

Temperature and Moisture.

Joachim (1926), working in Ceylon on a sandy loam with a sand content of 75 per cent. and adding the equivalent of 10 tons of various green manures per acre, found that (1), maximum nitrification occurred at the end of the sixth week; (2), provided sufficient rainfall is experienced and under ordinary tropical conditions, the effects of green-manuring from the nitrogen standpoint last only about six months; (3), the amount of nitrate present at any particular time in the green manure plots is dependent on the rainfall in the previous fortnight; and (4), the temperature curve, so far as was obtainable, follows the nitrate curve.

At South Johnstone, the low monthly mean temperature in July and the gradual increase to a maximum in February, together with the considerably greater quantities of green manures turned in under relatively dry winter conditions, resulted in nitrification reaching its peak in the puero plots after 12 weeks and in the centro plots after 14 weeks; with the other legumes the first peak occurred after 16 weeks and maximum nitrification did not take place until 27 weeks had elapsed, after which the wet season commenced.

Jenny (1941) pointed out that published nitrogen analyses of tropical soils show that some soils are low in organic matter because high temperatures hasten the decomposition of plant residues, whereas other soils in low latitudes are exceptionally rich in humus as a consequence of high yields of luxuriant flora. He stated that "reasoning based on van't Hoff's law should deal with soil types of comparable moisture and kinds of vegetation." With large

quantities of green manure—such as are obtained from puero—and a gradual rise of mean maximum temperature from 75·3 deg. F. in July to 92·7 deg. F. in February, an increasing rate of decomposition can therefore be expected.

No soil moisture determinations were made during the course of this experiment, but it is clear that there was sufficient moisture in the soil after the wet season, together with the rainfall experienced during July to November, to enable cconsiderable nitrification to occur. From November to early February the increased rainfall affected nitrification by depressing it immediately after heavy falls, and by producing a rapid rise in the rate of nitrification within three or four weeks after heavy rain until the wet season commenced.

Table 10.

NITRATE NITROGEN (MEAN OF TWO DETERMINATIONS) IN EACH LAYER OF SOIL IN EACH TREATMENT COMPARED WITH COWPEA.

Treatment.	Soil Layer.	Date of Sampling and Nitrogen in Parts per Million.						
		Aug. 14.	Sept. 9.	Oct. 1.	Oct. 27.	Nov. 28.	Jan. 13.	Mean.
	Inches.							
Fallow ..	0–6	5·2	11·8	40·0	85·0	18·7	108·0	44·8
	6–12	4·1	10·9	29·9	25·0	18·2	42·4	21·7
	12–18	1·2	2·2	10·9	5·4	13·3	18·3	8·5
	18–24	..	..	2·7	4·4	4·7	6·3	3·0
Calopo ..	0–6	39·2	42·0	96·7	119·8	42·0	187·0	87·8
	6–12	34·3	55·7	83·6	95·0	57·0	128·5	75·7
	12–18	7·2	15·3	21·2	10·8	26·8	56·1	22·9
	18–24	1·2	2·6	3·5	13·1	7·2	13·1	6·8
Centro ..	0–6	20·2	40·4	203·2	141·3	15·2	91·4	85·3
	6–12	26·4	61·7	83·0	46·3	49·0	70·3	56·1
	12–18	7·4	12·2	34·6	10·3	17·9	35·6	19·7
	18–24	3·3	4·5	13·0	4·6	5·0	7·0	6·2
Puero ..	0–6	110·0	130·0	395·6	335·0	120·0	253·5	224·0
	6–12	90·6	164·5	151·0	125·2	262·0	199·0	165·4
	12–18	16·3	24·9	30·9	29·0	130·5	79·5	51·8
	18–24	4·0	5·0	22·6	12·9	35·8	19·5	16·6
Stylo ..	0–6	22·3	33·5	85·0	120·7	9·1	134·5	67·5
	6–12	66·6	59·7	76·8	47·8	38·9	67·8	59·6
	12–18	7·0	30·1	23·1	13·4	24·5	32·4	21·7
	18–24	..	..	7·4	5·3	3·8	4·3	3·5
Cowpea ..	0–6	38·5	40·5	91·5	132·0	29·3	179·5	85·2
	6–12	31·7	27·0	51·0	27·2	44·3	89·2	45·1
	12–18	4·3	1·6	8·4	6·6	18·1	25·3	10·7
	18–24	1·8	1·4	8·4	5·7	7·7	8·1	5·5
Rainfall (Between Sampling Dates) in Inches ..		1·73	1·13	nil	0·02	6·23	2·73	..

COMPARISON OF NITROGEN AFTER COWPEAS AND AFTER TROPICAL PERENNIAL LEGUMES AND UNDER BARE FALLOW.

Concurrently with the soil sampling carried out in the perennial tropical legume plots described previously, samples were taken from two plots in an adjacent area of giant cowpeas. The cowpeas were ploughed under in June and the soil sampling was carried out in the same manner as with the tropical legumes but on alternate dates only from August 14, 1941, to January 13, 1942, giving a total of six samples at each of four different depths. Although the cowpeas were situated adjacent to the perennial tropical legume experiment they did not form part of it, and therefore the results cannot be examined statistically against the corresponding figures for the legume plots. However, as the soil type, the climatic conditions and the sampling dates were identical, it is of interest to compare the nitrate nitrogen values of the six samplings in the cowpea plots with the values calculated for the perennial tropical legumes and bare fallow on the same six dates. The values are shown in Table 10. The mean figures for calopo, centro and giant cowpeas in the 0–6 inch layer are practically the same; in fact, there is little difference between the nitrate nitrogen content for any layer—with the exception of the low figures for cowpeas in the 6–12 inch and 12–18 inch layers—of any of these three legumes or of stylo. Table 11 shows the mean nitrate nitrogen at four different depths for the four perennial tropical legumes, giant cowpeas and bare fallow for six sampling dates.

These figures suggest that (1), puero after 18 months' growth is greatly superior to giant cowpeas grown as a short-term summer green manure as a source of nitrate nitrogen under the conditions in the two plots; and (2), cowpeas are not superior to calopo, centro or stylo when the perennial legumes are grown for a period of 18 months. These results cannot be tested statistically, however, and a definite statement as to the relative merits of cowpeas and the various tropical perennial legumes must await further field experimentation.

NITROGEN CHANGES UNDER BARE FALLOW IN THE WET TROPICS.

From the results of the nitrate nitrogen determinations, summarized in Table 1, the following conclusions relative to the bare fallow plots may be drawn:—

(1) Nitrate nitrogen production did not commence until mid-August; i.e., 2½ months after the close of the wet season at the end of May.

(2) Production was slow until mid-September.

(3) The first peak in the surface 6 inches—equivalent to 85 p.p.m. of nitrogen—was reached at the end of October.

(4) Rainfall amounting to 6·23 inches in November caused heavy leaching from the surface 6 inches to lower soil layers and served to depress production of nitrate temporarily.

(5) The highest peak (108 p.p.m.) occurred on January 13—21 weeks from the time at which production commenced.

(6) The mean monthly maximum temperature increased steadily during this period of increasing nitrate content from 80·2 deg. F. in September to 91·3 deg. F. in January.

(7) From November onwards the increase in rainfall caused a considerable increase in soil moisture content, and after the temporary reduction in nitrate production referred to in (4) there followed a rapid rise in nitrate nitrogen content until the wet season commenced in February.

(8) The wet season served to inhibit the various factors which promote nitrate nitrogen production.

Table 11.

Mean Values for Nitrate Nitrogen for Six Sampling Dates at Four Different Depths for all Treatments.

Treatment.	Date.	No. of Determinations.	Mean Nitrogen p.p.m.			
			0–6 Inches.	6–12 Inches.	12–18 Inches.	18–24 Inches.
Fallow	14–8–41 to 13–1–42	6	44·8	21·8	8·6	3·0
Calopo			87·8	75·7	22·9	7·1
Centro			85·3	56·9	19·7	6·3
Puero			224·0	165·4	51·9	16·6
Stylo			67·5	59·6	21·8	3·5
Cowpea			85·2	45·1	10·7	5·5

The production of nitrate nitrogen in bare-fallowed soils may be ascribed to several factors, including the decomposition of residues of weeds and previous crops, the decomposition of humus, the deposition of inorganic nitrogen by rainfall, and the fixation of nitrogen by non-symbiotic bacteria. The quantity of nitrogen added as ammonia and nitrates through the agency of rain may be estimated at from 7 to 10·5 lb. per acre per annum, judging by results obtained in Ceylon (Koch, 1941, 1943) and in other parts of the tropics (Vageler, 1933). The data obtained in this experiment do not permit any estimate being made of the other three factors listed. It must be pointed out, however, that the periodic weeding of the bare fallow plots provided plant material in a readily decomposable form, and that the lime and fertilizer applications made before the experiment commenced provided conditions favourable to bacterial activity. The high content of nitrate nitrogen—108 p.p.m.—in the bare fallow plots on January 13 suggests that non-symbiotic nitrogen-fixing organisms may have been active during the summer months. Additions of available nitrogen variously estimated at from 15 lb. to 40 lb. per acre per annum under favourable conditions have been credited to various bacteria, including *Azotobacter* spp., although the figure is usually not more than 10 lb. No examination of the microflora of the soil of the experimental area was made, but neither soil nor climatic conditions would rule out the occurrence of nitrogen-fixing bacteria, as a species of Azotobacter capable of fixing nitrogen in acid

soils is known (Starky and De, 1939), and Azotobacter has a wide distribution in the tropical region of Malaysia (Corbet, 1935). But, as Waksman (1932) has pointed out: "in many cases, the actual amount of nitrogen fixed falls within the probable error for the determination of total nitrogen."

With respect to leaching, it is of interest to note that following five falls of rain totalling 5·14 inches spread over seven days prior to the sampling on November 11, the nitrogen content in the 12–18 inch layer was 20·5 p.p.m., an increase of 15·1 p.p.m. over the corresponding figure on October 27. On February 2, after eight falls of rain aggregating 5·72 inches spread over 15 days, the nitrate nitrogen content of the 12–18 inch layer was 26·9 p.p.m. and of the 18–24 inch layer 13·8 p.p.m.; these represent increases of 8·6 p.p.m. and 7·5 p.p.m. respectively over the corresponding values on January 13.

GENERAL DISCUSSION.

The outstanding facts which emerge from the investigation are:—

(1) The very high production of nitrate nitrogen which occurred over a period of seven months—from July to February—when a crop of puero 18 months old was ploughed under on a silty soil in the "wet tropics."

(2) The considerable nitrate nitrogen production which took place from mid-August to February in the bare fallow plots.

The effects of yield, composition, soil moisture and temperature on the rate and degree of nitrification have already been discussed in some detail. It remains, therefore, to consider the main implications of these results and their possible application.

A point of considerable importance in the building up of soil fertility under tropical conditions is the length of life of the legumes available for soil improvement purposes. Annuals are useful as temporary weed-smother crops and provide some available nitrogen for subsequent crops, and biennials offer distinct advantages over annuals; but loss of soil fertility under tropical conditions is often such that the most satisfactory method of bringing the soil back to good physical condition is by means of perennial legumes used as green manures. Furthermore, the fundamental importance of the grazing animal in building up soil fertility suggests that the optimum value of these perennial tropical legumes will probably be obtained when they are grazed under satisfactory management. Therefore, the ploughing under of perennial legumes should be preceded wherever possible by rotational grazing.

A further logical development would be the establishment of a temporary ley (Stapledon, 1939) to complete the building up of soil fertility before putting the land under crop again. Even under temperate conditions there is a necessity "for land being put down to grass for long periods if any prolonged gain in fertility is to result" (Richardson, 1938), and in the tropics the need is still more urgent.

Under conditions in the "wet tropics," puero—which is closely related to kudzu and is in fact its tropical counterpart—has proved to be a legume of outstanding value. It is used extensively in Malaya and Sumatra as a plantation cover crop to assist in maintaining soil fertility and in the prevention or control of erosion, and its ability to withstand light shade has extended its usefulness considerably. The results obtained in this experiment demonstrate that large quantities of nitrate nitrogen are produced rapidly during its decomposition after ploughing under a crop grown for 18 months; and this is quite apart from its value as a source of humus, which would not be inconsiderable.

Puero is easy to establish from seed or cuttings, and it is so aggressive that it has been used successfully as a weed-smother crop. Puero roots freely at the nodes under suitable conditions and forms a carpet over 2 ft. deep, completely covering the soil, shading it from the sun, preventing the direct impact of rain, and ensuring adequate protection against soil erosion. It is a rather shy seed-bearer, and thus little trouble from self-regeneration occurs when an area of the crop is ploughed and the land placed under cultivation. The beneficial effect on soil structure of the organic residues from the various legumes, especially puero, is a further factor of the utmost importance. West and Howard (1938) have pointed out that the structure of the soil under legumes was definitely better than under clean cultivation.

Puero is palatable and may be of special value as a pioneer legume in the rehabilitation of rain-forest areas which have been opened and planted to grass, but where the topography precludes ploughing as a means of overcoming weed-infestation prior to replanting. It may in addition be used with advantage on areas where ploughing can be undertaken, but where the soil is low in nitrogen and humus and weeds have taken possession; that is on worked-out, washed-out, "dead" soils. Experimental work has indicated that the planting of single or double-furrow strips, 10 ft. to 15 ft. apart on the contour, may be sufficient to allow puero to become established and smother out the weeds.

The results of this experiment indicate the unsuitability of stylo as a green-manure crop; it is, however, a very promising pasture legume. Calopo grows rapidly and seeds freely under conditions in the "wet belt" of coastal northern Queensland, and it shows promise as a short-term, summer-growing green manure. Centro possesses a wide climatic range of tolerance. Its ability to form a carpet of cover within six months on some of the poorer soils of the coastal belt as far south as Brisbane without fertilizer application, combined with its aggressive hardy nature and capacity to withstand coastal frost (although the young foliage and stems are killed), demonstrate the potential value of this species for erosion prevention or control, green-manuring and pasture work along the coastal fringe of Queensland.

The data given in this experiment for nitrate nitrogen production under bare fallow offer a partial explanation of the extremely rapid vegetative growth which is typical under coastal conditions in northern Queensland from November to March (Schofield, 1944). The steady increase of nitrate nitrogen from mid-August to mid-January, when the maximum is reached, combined with

increased temperature, length of day, and rainfall, appear to be the factors which determine this rapid vegetative growth.

It is a matter of common observation in the maize-growing area of northern Queensland that, should there be even a slight delay in the planting of maize after the first good rain, the subsequent crop is much inferior to that planted immediately after good rain. The high concentration of nitrate nitrogen in the 0–6 inch and 6–12 layers of the soil prior to heavy rain, and the subsequent leaching effect which occurs when the heavy rains of the wet season commence, may explain this difference in growth.

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REFERENCES.

AKHURST, C. G. 1932. The carbon and nitrogen contents of some natural covers. J. Rubber Res. Inst. Malaya 4 (2): 131-9.

ALLEN, O. N., and ALLEN, E. K. 1936. Root nodule bacteria of some tropical leguminous plants. I. Cross-inoculation studies with *Vigna sinensis* L. Soil Sci. 42 (1): 61-76.

———————. 1939. Root nodule bacteria of some tropical leguminous plants. II. Cross-inoculation tests within the cowpea group. Soil Sci. 47 (1): 63-76.

AQUINO, D. I., and MADAMBA, A. L. 1939. A study of root nodule bacteria of certain leguminous plants. Philipp. Agricst. XXVIII (2): 120-32.

BEELEY, F. 1938. Nodule bacteria and leguminous cover plants. J. Rubber Res. Inst. Malaya 8 (2): 149-62.

COCHRAN, W. G. 1938. Some difficulties in the statistical analysis of replicated experiments. Emp. J. Exptl. Agric. VI (22): 157-75.

CORBET, A. S. 1935. Biological Processes in Tropical Soils With Special Reference to Malaysia. Cambridge: W. Heffer and Sons Ltd.

FAULKNER, O. T. 1934. Some experiments with leguminous crops at Ibadan, Southern Nigeria, 1925-33. Emp. J. Exptl. Agric. 2 (6): 93-102.

JENNY, H. 1941. Factors of Soil Formation. New York: McGraw Hill Book Company Inc.

JOACHIM, A. W. R. 1926. A further report on the rate of decomposition of green manures under Peradeniya conditions. Trop. Agricst. LXVII (4): 231-6.

———————, 1931. A Manual of Green Manuring. Colombo: H. W. Cave and Company.

JONES, G. H. G. 1942. The effect of a leguminous cover crop in building up soil fertility. E. Afr. Agric. J. VIII (1): 48-52.

KOCH, D. E. V. 1941. The nitrogen content of Ceylon rain. Trop. Agricst. XCVII (2): 74-7.

———————. 1943. The nitrogen content of Ceylon rain. Trop. Agricst. XCIX (1): 18-19.

PARBERY, N. H., and SWABY, R. J. 1942. The efficiency of organic materials in supplying nitrogen to crops. Agric. Gaz. N.S.W. LIII (8): 357-61.

POSADAS, S. S. 1941. A study of root-nodule bacteria of certain leguminous plants. Philipp. Agricst. XXX (3): 215-26.

RICHARDSON, H. L. 1938. The nitrogen cycle in grassland soils: with especial reference to the Rothamsted Park grass experiment. J. Agric. Sci. XXVIII (1): 73-121.

RUSSELL, E. J. 1936. General survey of the use of green manures. *In* Use of Leguminous Plants in Tropical Countries as Green Manure, as Cover and as Shade. Rome: International Institute of Agriculture.

SCHOFIELD, J. L. 1941. Introduced legumes in North Queensland. Qld. Agric. J. LVI. (5): 378-88. (Reprinted 1941 as Comm. from Bur. Tropical Agric. Grassland Ser. No. 1.).

———————. 1944. The effects of season and frequency of cutting on the productivity of various grasses under coastal conditions in northern Queensland. Qld. J. Agric. Sci. 1 (4); 1-58. (Reprinted 1944 as Comm. from Bur. Tropical Agric. Grassland Ser. No. 2).

STAPLEDON, R. G. 1939. The Plough-up Policy and Ley Farming. London: Faber and Faber Ltd.

STARKEY, R. L., and DE, P. K. 1939. A new species of *Azotobacter*. Soil Sci. 47 (4): 329-43.

THOMPSON, F. B., and COUP, M. R. 1943. Studies of nitrate and ammonia in soils under permanent pasture. N.Z.J. Sci. Tech. 25 (3A): 118-124.

VAGELER, P. 1933. An Introduction to Tropical Soils. London: Macmillan and Co., Ltd.

WAKSMAN, S. A. 1932. Principles of Soil Microbiology. London: Bailliere, Tindall and Cox.

THE EFFICIENCY OF CHARCOAL COOLERS FOR HOLDING CREAM ON FARMS.

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INTRODUCTION.

For some considerable time charcoal coolers have been used for the holding of cream on dairy farms in the Wowan district, which is situated south-west of Rockhampton. Investigations were conducted during February and March, 1945, for the purpose of ascertaining the requirements in design and construction, the procedure needed for most efficient operation, and the possibility of extending the area of profitable use of such coolers. As a result of the investigations it has been possible (Few, 1945) to indicate to farmers the range of usefulness of charcoal coolers, details of their design and construction, and particulars regarding their use. The purpose of this paper is to present and discuss the data secured.

SCOPE OF THE INVESTIGATIONS.

The investigations were carried out in three series, dealing respectively with (1) the efficiency of cooling in a standard type of cooler; (2) the effect of a flue vent on the efficiency of cooling; and, (3) check tests on coolers in use on farms.

EFFICIENCY OF COOLING IN A STANDARD-TYPE COOLER.

The observations on cooling in a standard-type cooler were carried out over a 24-hour period in late February. The weather was fine, with the daytime temperatures normal and the night temperatures slightly below the average for late summer. The humidity during the daytime was above the average, because of a fall of two inches of rain two days previously, and consequently the degree of cooling possible under normal conditions of humidity would not be lower than that secured on the testing day.

Technique.

Immediately following the separation of the cream after the morning milking of the herd, a can of cream was placed in the cabinet of the test cooler, and it was held there for 24 hours. A control can of water was held during the same period in the dairy house in which the cream would normally be kept if no charcoal cooler were available. Water was used in the control can because there was insufficient cream for the purpose, but it is considered that the difference in behaviour between cream and water would not be large enough to vitiate the validity of the comparisons made.

Atmospheric shade temperature readings were made in the farmhouse, situated about 50 feet from the cooler, and in the dairy house located about 220 feet from the farmhouse. The thermometers used were checked to read to 1 deg. F. An hygrometer checked to within 1 per cent. was exposed in a shaded position at the farmhouse, and some readings of an hygrometer placed in the cool chamber were also secured. Relative humidity was determined by the use of modern Carrier psychrometric charts.

Discussion of Data.

The data obtained are recorded in Table 1 and are shown in graphical form in Figure 1.

Table 1.

DATA ON THE EFFICIENCY OF COOLING.

Time.	Atmospheric.			Dairy Shade Temperature. (Near Can.)	Cooler Cabinet Temperature.	Cream Temperature.	Temperature of Can in Dairy.	Cooler Cabinet Relative Humidity.
	Shade Temperature.	Relative Humidity.	Wet-bulb Temperature.					
	°F.	Per cent.	°F.	°F.	°F.	°F.	°F.	Per cent.
9.00 a.m. ..	81	62	70·8	78	71	85	83	..
9.30 a.m. ..	83	59	71·6	80	71	84	82	..
10.00 a.m. ..	85	56	72·4	84	70	83	82	..
10.30 a.m. ..	86	54	73·0	86	70	82	82	..
11.00 a.m. ..	88	50	73·2	89	70	80	83	84
11.30 a.m. ..	88	48	72·4	91	70	80	83	86
12 noon	89	48	73·2	91	70	79	83	88
12.30 p.m. ..	90	47	73·5	91	73	79	84	..
1.00 p.m. ..	93	48	76·6	91	73	78	84	86
1.30 p.m. ..	92·5	45	75·0	92	73	78	85	88
2.00 p.m. ..	92·5	44	74·3	92	72	78	86	91
2.30 p.m. ..	92	44	74·0	94	72	78	86	90
3.00 p.m. ..	90	44	72·5	90	73	77	87	92
5.30 p.m. ..	89·5	43	71·7	90	70	75	84	96
8.00 p.m. ..	78	64	69·0	79	71	75	82	..
7.00 a.m. ..	70	90	68·0	74	70	74	72·5	80
9.00 a.m. ..	80	75	73·6	85	70	74	74	82

The temperature-time line A in Figure 1 shows the variation in the wet-bulb temperature over the 24-hour period; the highest value is 76.6 deg. F. at 1.00 p.m. and the lowest 68.0 deg. F. at 7.00 a.m. This line represents the maximum degree of cooling theoretically possible by the adiabatic evaporation of water from a wetted surface into the surrounding atmosphere.

The temperature-time line B shows the temperatures within the cabinet during the 24-hour period. When considered in relation to line A it may be regarded as the efficiency line for the cooler, as it shows the relationship between the actual temperature realized and the existing wet-bulb temperature. In examining the two lines, however, it must be realized that small temperature differences are not significant, due to personal errors in reading the instruments and to the fact that the thermometer error is ± 1 deg. F., and that there is

also a possible error of 1 per cent. in humidity values. The temperature remained quite constant within the cabinet till 12.30 p.m., when it suddenly rose 3.0 deg. F. During this time the wet-bulb temperature had gradually risen for the most part until at 12.30 p.m. it was practically the same as the cooler temperature.

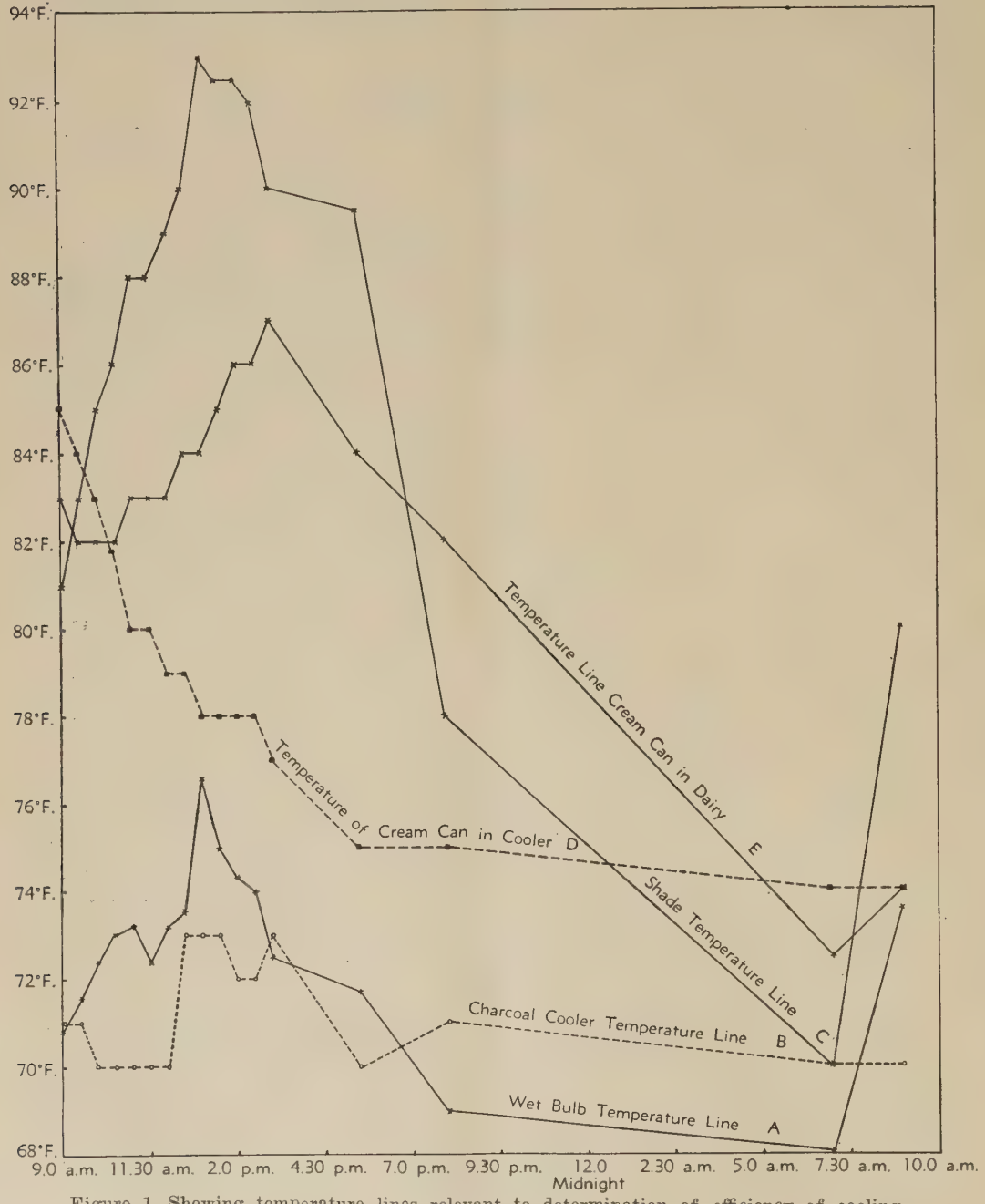

Figure 1. Showing temperature lines relevant to determination of efficiency of cooling.

The practice on the farm on which the work was conducted was to water the charcoal early in the morning and again at midday, and the second watering was given immediately aftr recording the noon readings. During the three hours from 9.00 a.m. to noon the charcoal was relatively dry; its insulating effect is apparent, as the cabinet maintained the wet-bulb temperature corresponding to atmospheric conditions existing at the time of the early morning watering. Between noon and 12.30 p.m., the wet-bulb temperature was slightly over 73.0 deg. F., and this accounts for the sudden rise of 3.0 deg. F. in the cooler temperature following the impairment of the insulating effect of the charcoal by the midday watering. The conclusion to be drawn from the data is that the charcoal has a definite insulating value, enabling the retention of a uniform temperature despite possible fluctuations in wet-bulb readings. As the lowest wet-bulb temperature usually occurs during the night or early in the morning, it is most practicable to water thoroughly at such times and to refrain from further watering during the day. This can be taken as a general rule applicable to the average charcoal cooler. In cases where poor design results in relatively inefficient insulation, the temperature may rise during the day, and in such cases watering may be necessary to reduce the cabinet to the existing wet-bulb temperature. The insulating value of a well-constructed cooler is also apparently realized very shortly after watering, as the temperature of 73.0 deg. F. in the cooler was maintained despite the rise in the wet-bulb reading to 76.6 deg. F. at 1.00 p.m. Between 5.30 p.m. and 8.00 p.m. the two lines cross on the graph, showing that, due to a similar insulating effect, the cabinet did not fall to the wet-bulb temperature. From the sanitary viewpoint it is likewise considered inadvisable to open up the cabinet or remove the cream from the cooler overnight. The atmospheric temperature during the night may fall below the evening cooler temperature, but the time lag in cooling a can of cream is so great that the value of removing the cream cans is more apparent than real. During the night of the tests the atmospheric temperature fell to 60.0 deg. F. (as determined by a minimum temperature thermometer), but the control can in the dairy house was down to only 72.5 deg. F. by 7.00 a.m. The atmospheric temperature of 60.0 deg. F. is not recorded on the shade temperature line, as no direct readings were made between 8.00 p.m. and 7.00 a.m.

The temperature-time line C shows the shade temperature at all times when readings were made, and when compared with line B indicates the degree of cooling obtained in the cooler. The maximum difference between atmospheric and cooler temperatures is 20.5 deg. F. at 2.00 p.m. Atmospheric shade temperature readings are of special significance only when taken in conjunction with relative humidities, the wet-bulb temperature being the important value. As a consideration of lines A and B has shown that, allowing for temperature lags due to insulation, wet-bulb temperatures are attained in charcoal coolers, it follows that charcoal coolers will be effective in any locality where the shade temperatures and relative humidity are such that the wet-bulb temperature does not exceed 70.0 deg. F.

The temperature-time line D shows the progressive cooling of the cream can placed in the cooler at 9.00 a.m. following separation after the morning milking. The most obvious and important feature is the slowness of cooling: at no time during the 24 hours was the cream temperature down to the desired level of 70.0 deg. F. After 11 hours in the cooler the cream temperature fell by 10.0 deg. F., with a further 5.0 deg. F. possible. Thereafter the rate of fall is insignificant, and this occurs when the temperature difference is no greater than 5.0 deg. F. The cream was stirred on each occasion before the temperature was taken, and this would be likely to increase the rate of cooling. Ordinarily the cream is stirred only once or twice during the day to allow any accumulation of gas to escape, and it can be assumed that under such conditions the cream remains at too high a temperature for a lengthy period after first being placed in the cooler cabinet. A suitable method for initial cream cooling is therefore required if cream quality is to be satisfactorily preserved in the cooler.

The temperature-time line E shows the lag in heating of the can stored in the dairy house and also the failure of the can to respond readily to a fall in atmospheric temperature. The line does, however, run roughly parallel with the shade temperature line, the lag in heating and in cooling being apparent. It will be noted that the point at which cooling commences is theoretically impossible, as at that time the shade temperature is actually 3·0 deg. F. above the temperature of the water in the can. This effect is due to evaporative cooling of the water in the can itself, the can being kept with the lid off, following the usual practice with cream on the farm. The relative cooling of the can in the cooler with respect to that in the dairy would thus be greater if cream had been used in the control can, while the early fall in temperature of the can of water follows the fall in the wet-bulb temperature, which becomes quite definite after 1·00 p.m.

A comparison of lines D and E shows clearly the degree of cooling that can be expected by the use of charcoal coolers even if the cream is not cooled before being placed in the cabinet. Over the second day of cream holding, when such is necessary, the value of the cooler would obviously be greater, as little variation in cream temperature would occur after the first 12 to 24 hours of storage.

EFFECT OF A FLUE VENT ON THE EFFICIENCY OF COOLING.

A test was carried out with the main object of determining if the flue vent as ordinarily fitted to charcoal coolers is necessary. The need for such a vent was a matter of doubt, as the cooler air within the chamber is denser than that normally outside, and as a result there would be no tendency for a movement of this air from the cabinet through the flue. It was also commonly suggested that the higher the flue the better the results. This is obviously fallacious, as, even with a furnace chimney, there is an economic height, and a loss in efficiency and draught results if the height is either increased or decreased. Thus, although the necessity for a flue in charcoal coolers was doubted, it was

decided that if this deduction was incorrect it should be possible to determine an economic flue height to achieve the maximum degree of cooling in the cabinet.

Technique.

In view of the deductions from the experiment on the efficiency of cooling, the charcoal was watered early in the morning and was not further treated until after the last readings had been taken on the following morning. The cooler employed was the one used in the investigation just reported. The inside cabinet was substantially air-tight except for the two charcoal sides and the flue situated at the top of the back wall of the cabinet. The flue was of galvanized iron, with the joints soldered, and was 20 feet high and 4 inches in diameter. The flue was completely blocked at 7·00 a.m. to prevent any air circulation, and observations were made over the ensuing period of 26 hours.

Table 2.

DATA ON THE EFFECT OF A FLUE VENT ON THE EFFICIENCY OF COOLING.

Time.	Atmospheric.			Cooler Cabinet Temperature.	Cooler Cabinet Relative Humidity.
	Shade Temperature.	Relative Humidity.	Wet-bulb Temperature.		
	°F.	Per cent.	°F.	°F.	Per cent.
7.00 a.m.	70	90	68·0	70	80
9.00 a.m.	80	75	73·6	70	82
12 noon	91	50	75·7	73	over 100
2.00 p.m.	91	45	73·9	74	over 100
5.00 p.m.	86	48	70·8	73	..
9.00 a.m.	82·5	69	74·4	72	..

Discussion of Data.

The data given in Table 2 show that the cooler cabinet remained at the wet-bulb temperature, except that the insulating effect prevented a rise when the wet-bulb temperature rose, and a fall with the lowering of that reading. Although observations were not continued over a long period or under various atmospheric conditions, it appears reasonable to assume that a direct draught, if such could be produced by a flue, is actually unnecessary to enable cabinet temperatures to be reduced to the wet-bulb reading. A point considered to be of significance is the rise of 3·0 deg. F. in cabinet temperature shown at noon. A breakdown in the insulation value of the charcoal seems the most likely explanation, although this was not as complete as the breakdown in the previous experiment, when the charcoal was thoroughly wetted at the same time. The cabinet humidity was over 100 per cent. at noon, showing that the air within actually contained water droplets in suspension in addition to being saturated with water vapour in the gaseous form. The insulating value of a relatively dry medium would undoubtedly be impaired by the presence of air in such a condition, and this is considered to be the reason for the temperature rise. That it could not be due to lack of insulation of the charcoal itself is shown from the previous experiment, and also from the fact that despite the rise of 3·0 deg. F.

Table 3.

DATA OBTAINED FROM VARIOUS FARM CHARCOAL COOLERS.

Farm.	Date.	Time.	Atmospheric.			Cooler Cabinet.		Remarks.
			Shade Temperature.	Relative Humidity.	Wet-bulb Temperature.	Temperature.	Relative Humidity.	
			°F.	Per Cent.	°F.	°F.	Per Cent.	
W. J. Thomas, Walmul..	27–2–45	10.30 a.m.	89	65	78·9	79	74	Humidity higher than usual due to rain falling on previous day. Flue on cooler 2 in. diam.; 8 ft. high. Charcoal watered immediately after 10.30 a.m. readings. Cooler situated in shed with sloping roof.
		11.00 a.m.	89	61	77·8	78	92	
E. Harris, Wowan ..	27–2–45	12.15 p.m.	93	60	81·3	78	84	Charcoal watered during early part of morning. Flue on cooler 4 in. diam.; 20 ft. high. Cooler situated in open.
		2.30 p.m.	95	54	80·6	77	100	
V. Kearney, Deeford ..	1–3–45	2.55 p.m.	90	50	74·8	86	..	Cooler not used for some time. Flue on cooler 5 in. diam.; 13 ft. high. Cooler situated in shed. Charcoal watered immediately after 2.55 p.m. readings.
		3.10 p.m.	90	50	74·8	75	..	
L. M. Holbing, Deeford..	1–3–45	4.15 p.m.	87·5	54	74·3	72·5	..	Cooler situated in shed. Flue 3 in. diam; 15 ft. high.

in temperature the cabinet is still significantly below the existing wet-bulb temperature. The use of a vent does prevent the air in the cabinet from exceeding 100 per cent. relative humidity, as the figures from the previous experiment indicate. This is true despite the thorough watering of the charcoal at noon, after which time the humidity within the cooler cabinet rose gradually, but did not reach the 100 per cent. level. It can thus be considered sound practice to include a vent in the design of charcoal coolers, not for actual cooling purposes but to avoid excessive humidities likely to impair the insulation of the unit. From the point of view of hygiene it is likewise considered desirable. No flue pipe is really necessary, but the provision of a pipe two or three feet in length is desirable in order that water will not be poured into the cabinet through the vent during charcoal wetting operations.

CHECK TESTS ON FARM COOLERS.

Check tests were made on a number of charcoal coolers in the district, and the results confirm the validity of the general conclusions reached. The cooler used for the experiments so far described was included in these trials, and the data for all coolers are given in Table 3.

Allowing for the insulating effect of the charcoal surrounding the cooler cabinet, the temperatures in all cases are substantially the same as the wet-bulb readings. In the case of the one cooler not being used, the wet-bulb temperature was attained within 15 minutes after thoroughly wetting the charcoal, despite the fact that this involved a reduction of 11 deg. F. in temperature. The location of the coolers is unimportant, since those situated in the open showed the same degree of cooling as the shaded coolers.

REFERENCE.

FEW, F. G. 1945. Charcoal coolers on dairy farms. Qld. Agric. J. 60 (5): 302-10.

A. H. TUCKER, Government Printer, Brisbane.